Autonomous Forced Landing System for Light General Aviation Aircraft in Unknown Environments

Bilal Arain, Michael Warren, Xilin Yang, Felipe Gonzalez, Luis Mejias and B. Upcroft

This paper presents a system enabling a light general aviation aircraft to land autonomously in case of an unscheduled event such as engine failure. The proposed system will not only increase the level of autonomy for general aviation aircraft industry but also increase the level of dependability. Safe autonomous landing in case of an engine failure with certain level of reliability is the primary focus of our work as both safety and reliability are attributes of dependability. The system is designed for a light general aviation aircraft but can be extended for dependable unmanned aircraft system.

The underlying system components are computationally efficient and provides continuous situation assessment in case of an emergency landing. The proposed system is undergoing an evaluation phase using an experimental platform (Cessna 172) in real world scenarios. Forced landing procedure is not new to the aviation industry.

All pilots are required to perform forced landings as part of their training and according to the emergency procedure by the Civil Aviation Safety Authority (CASA) in Australia. Usually, the pilot performs visual navigation and subjective judgment to maneuver the aircraft for possible landing sites, knowing the best glide speed and the wind direction, in case of an emergency situation. Although the aircraft sensors and the weather station forecasts provide valuable information for visual navigation, yet the procedure heavily relies on the pilot judgement and training experience to locate a suitable landing site that has particular features such as size, shape, surface, slope, surroundings for safe landing. Perhaps, the most difficult part to perform forced landing is to select a suitable landing site within the gliding range of an aircraft. The glide performance is specific to the aircraft, however, to reach the suitable site within limited time is not always guaranteed.

Indeed, the forced landing of larger passenger aircrafts such as UA 1549 in Hudson river and Air Canada Flight 143 at gimli industrial park are few such examples to emphasise the need of autonomous system. Aviation industry realises that the solution to this problem is fundamental to ensure the safety of crew and passengers.

This paper describes the system which enables a general aviation aircraft to perform forced landing in an unknown environment. This research work is part of the project ResQu, which is an abbreviation of Resilient Queensland. The project is a joint research program between Boeing Research & Technology (BR&T) Australia and the Australian Research Centre for Aerospace Automation (ARCAA). The objective of this project is to research and development number of enabling technologies, which are necessary to adapt Unmanned Aircraft Systems (UAS) in civilian airspace. The project ResQu is divided into four streams: 1) sensing and platform automation for miconia application; 2) risk and regulation research; 3) detect and avoid, and 4) automated emergency landing system. This paper presents research work related to the emergency landing system only. The description of other streams in Project ResQu is beyond the scope of this paper. The three main system components are Site Detection System (SDS), Multi-Criteria Decision Making (MCDM) system, and Guidance, Navigation & Control (GNC) system. A brief overview of each sub-system is given in the following paragraphs.

The SDS actively monitors the environment below the aircraft to detect safe, flat zones and characterises them according to environment type, shape, size, nearby obstacles and proximity to civilisation. Using a downward facing camera capturing at high frame-rate, the site detection system actively tracks features on the ground to generate an estimate of both 3D scene structure and the pose of the aircraft. Leveraging the performance of a high-power GPU, the SDS then performs dense depth mapping using the captured imagery to produce textured, high-quality reconstructions of the ground below the aircraft. By then applying shape and size heuristics the SDS finds and then forwards high likelihood landing sites to the MCDM system to determine the most appropriate site to approach in an emergency.

Over the past years, ARCAA is involved in developing SDS for an automated emergency landing system. In [1], site selection system has been tested and evaluated using flight test data. The proposed system locates landing sites by segmenting images into areas that are suitable for landing a GA aircraft such as Cessna 172. These preliminary landing sites are then evaluated and classified for surface types, slope information and other additional attributes which may be required for safe landing. This evaluation and classification is then fused together to select a final candidate landing site. While this system has been tested successfully, the undergoing research is to obtain the final candidate site with

B. Arain, M. Warren, X. Yang, F. Gonzalez and Luis Mejias are with the Australian Research Centre for Aerospace Automation (ARCAA) and Queensland University of Technology (QUT), Brisbane, Australia Email: bilal.arain, michael.warren, x.yang, felipe.gonzalez, luis.mejias@qut.edu.au

B. Upcroft is with the School of Electrical Engineering and Computer Science, Queensland University of Technology (QUT), Brisbane, Australia. Email: ben.upcroft@qut.edu.au

The research presented in this paper forms part of Project ResQu led by the ARCAA. The authors gratefully acknowledge the support of ARCAA and the project partners, QUT; CSIRO; Queensland State Government; Boeing and Insitu Pacific

3D terrain characterisation from imagery in remote and urban areas [2].

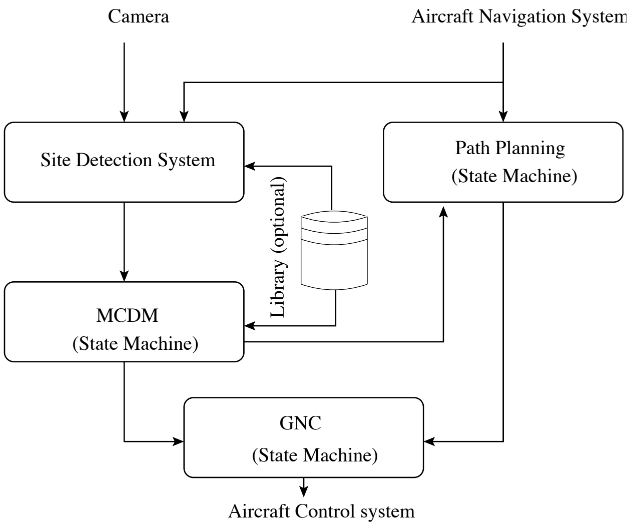

Fig. 1: Block diagram of the autonomous forced landing system.

Recently, a vision based system has been proposed in [3], this system allows an aircraft to fly towards a known landing site or nearby airfield using a database such as En-Route Supplement Australia (ERSA). In practice, it is not possible to always find an airfield in case of an onboard emergency. It is also worth mentioning here that the flight instructors usually pilots perform forced landing in unknown areas (or environment), where there is no prior knowledge available to the pilot. Therefore, it is utmost necessary to demonstrate a solution which can work not only in an unknown environment but can work around the clock and in all weather conditions. Note that the proposed solution in [3] can be used in a situation where active site detection system (vision based system) cannot work such as in cluttered environment, etc. In case of an emergency landing, one of the important decision to make by the pilot is to choose a suitable landing site within a gliding range of an aircraft. The site detection system may provide more than one feasible landing sites, therefore a decision has to be made based on the attributes of the location. The MCDM system will anticipate to decide on a feasible landing site, from the available set of site locations provided by the SDS. The MCDM aims to automate the landing site selection process by using high level reasoning on multiple criteria such as wind, surroundings, size, surface, slope, and civilisation during the forced landing procedure. A literature survey about the multi-criteria decision analysis methods such as outranking methods and expected utility methods are presented in [1] (see references therein for more details).

An intuitive approach to re-plan the UAS path, based on simulated decision making process, is presented in [4]. The proposed re-planning algorithm alters the pre-defined path from the current location of the aircraft and create a new path to a different landing site. However, the decision making process has not considered in the complete system. It was assumed to be calculated by the MCDM system a priori and were located one-third of the way into the landing sites. It was also assumed that the preferred directions of approach for landing site is known and have been calculated by the MCDM. The complete system was verified in flight tests, but the aircraft position was altered due to cross winds. Simulations showed that the re-plan phase was initiated based on a distance threshold from the final landing site. A GNC system which can generate dynamically feasible path to follow by the aircraft autonomously is an essential component of the autonomous emergency landing system.

In [4], 3D Dubins Curves path planning algorithm has been proposed for fixed-wing aircraft in case of an engine failure. The algorithm has been tested in simulations for path traversability while maintaining the aircraft stability. The work also extended the existing guidance algorithms to include wind information for an aircraft to follow a path without penalising the performance. The structure of the complete system is shown in Figure 1. The aircraft navigation information is required as an input to the SDS for geometric corrections of the imagery.

The SDS and, subsequently, MCDM should provide the location of the suitable landing suite within limited time and above certain altitude threshold. In case of any of the two systems could not provide the information, pre-defined library such as ERSA can be used to perform safe landing.

The GNC system framework, which supports real-time path planning and waypoint navigation, is based on Extended State Machine (ESM). Note that interaction between the system modules such as MCDM and GNC is also controlled by a state machine. The ESM framework is based on a specification language which allows component-based real-time implementation of complex systems [5].

In conclusion, this paper has presented a system which will add another level of safety and reliability for GA aircrafts and will also remove pilot workload in case of an emergency situation.

REFERENCES

[1] L. Mejias, D. L. Fitzgerald, P. C. Eng, and L. Xi, "Forced landing technologies for unmanned aerial vehicles : towards safer operations," in *Aerial Vehicles*, L. T. Mung, Ed. Kirchengasse, Austria: In-Tech, January 2009, pp. 413–440. [Online]. Available: http://eprints.qut.edu.au/42556/

[2] M. W. ans D. McKinnon, H. He, A. Glover, M. Shiel, and B. Upcroft, "Large scale monocular vision-only mapping from a fixed-wing uav," in *8th International Conference on Field and Service Robotics*, Matsushima, Japan, 2012.

[3] P. Williams and M. Crump, "Intelligent landing system for landing uavs at unsurveyed airfields," in *28th International Congress of the Aeronautical Sciences*, Brisbane, Australia, 2012.

[4] P. C. Eng, "Path planning, guidance and control for a uav forced landing," Ph.D. dissertation, Queensland University of Technology, 2011. [Online]. Available: http://eprints.qut.edu.au/43898/

[5] T. Merz, P. Rudol, and M. Wzorek, "Control system framework for autonomous robots based on extended state 177 machines,," in *International Conference on Autonomic and Autonomous Systems*, Washington D.C. USA, 2006.